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Second Quarterly Report

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PHYSICAL PROPERTIES OF LEAD SELENIDE FILMS

Contract NOw 62-0925-c
Section A, Item 2
For the Period
27 September 1962 to 27 December 1962

10 February 1963

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Second Quarterly Report

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I PROGRAM ACCOMPLISHMENTS

TEMPERATURE DEPENDENCE OF PbSe DETECTOR PERFORMANCE

The temperature dependence of resistance and sensitivity of cooled PbSe detectors has been previously determined. However, previous measurements did not include the variation of photoconductive lifetime and spectral characteristics with temperature. This type of information should be coupled with D^* and resistance measurements in order to obtain a more understandable correlation of the results.

Non-Ohmic Behavior

The non-ohmic performance of PbSe films has been reported many times. Some of this work has been described in previous reports connected with this program and is also reviewed in the Proceedings of IRIS¹.

There has been some uncertainty in the past as to whether all of the deviation from ohmic behavior was caused by Joule heating. This effect has been reevaluated with techniques other than the variation of the current pulse duty factor to detect the presence of heating.

The first experiment was performed to determine the current-voltage behavior of a standard detector at three different coolant temperatures, viz:

- a) liquid nitrogen (77°K),
- b) liquid oxygen (90°K),
- c) Freon 14 (145°K).

A typical result of this sort of experiment is shown in Fig. 1. The interpretation of these results is that Joule heating probably starts at the point where a significant deviation from the ohmic line is observed. Since most of the heat dissipation is by conduction through the glass substrate (~ 1 mm thick) and the glass cold finger (~ 1 mm thick), one can expect a significant temperature

gradient to appear. The exact three-dimensional heat flow situation is complex and will not be analyzed here. An approximate one-dimensional heat flow analysis predicts a significant temperature gradient will occur at the power where deviation from ohmic performance is observed. Note that as one raises the refrigerant temperature, a higher bias power can be tolerated before serious deviation from ohmic behavior is observed. This increase in bias power is qualitatively in agreement with the fact that the thermal conductivity of the glass increases significantly as the temperature is raised. The points shown as crosses on the three curves represent the bias conditions where the D^* was the same for all three refrigerants. Additional measurements showed that the photoconductive lifetime τ was also the same at these three points. In addition, the dynamic resistance (dV/dI) values obtained at these points are the same.

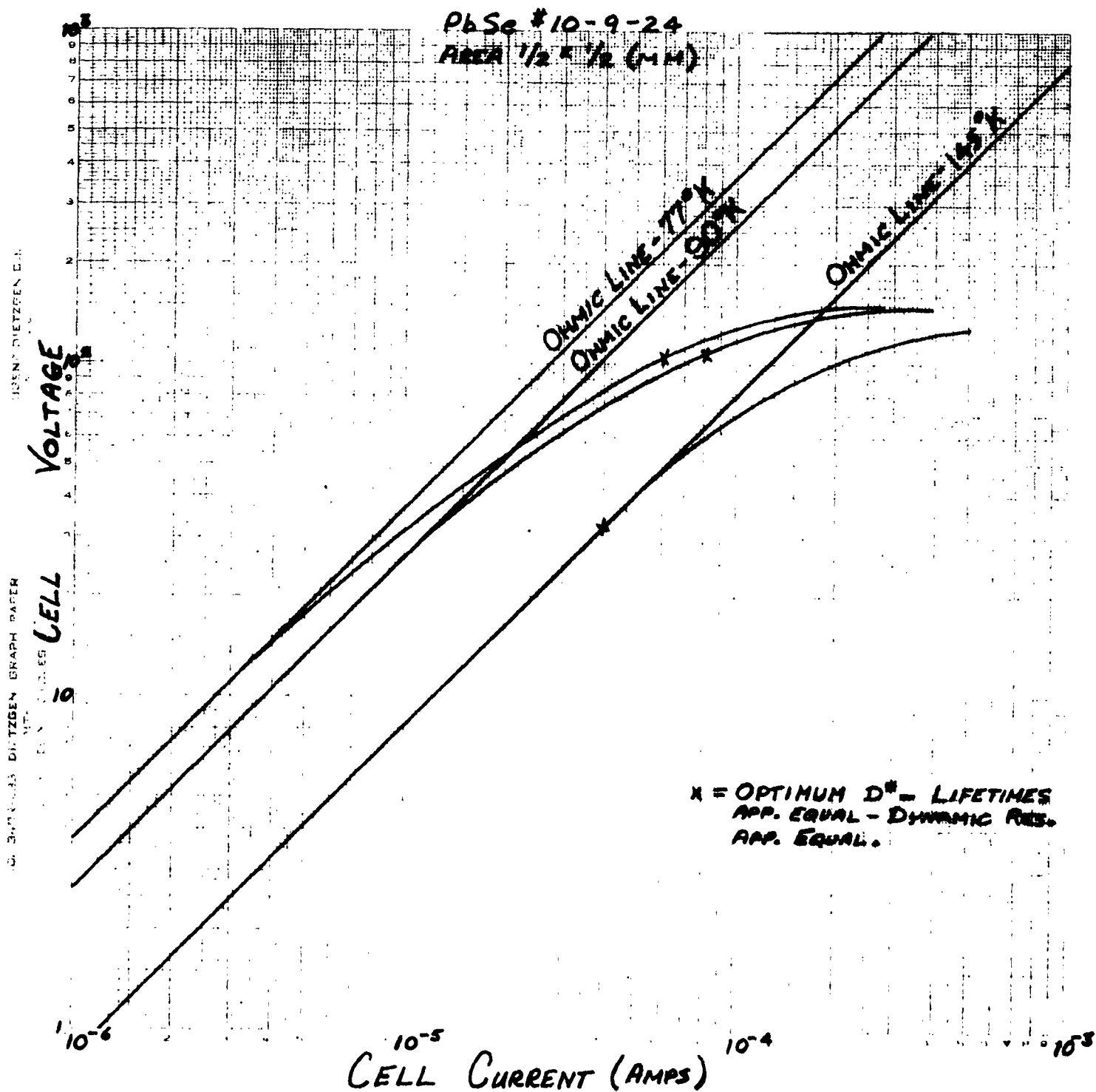
From this evidence one is forced to conclude that the true temperature of the film is the same at optimum D^* and independent of the refrigerants. Of course, a higher bias power (VI) is necessary to achieve this optimum temperature when the low temperature refrigerants are used. The apparent inversion between the 77°K and 90°K points is probably within the scatter of experimental errors in determining the optimum D^* , since D^* and τ do not vary greatly below about 145°K as will be shown later.

A test of the bias criterion described by Bode² at the San Diego IRIS meeting can be made from the 77°K data in Fig. 1. The power dissipated in the element at optimum bias is 6×10^{-3} watts. The square root of the element area is 5×10^{-2} cm. Hence $P/A^{1/2}$ is 0.12 watts/cm which falls within the range of the empirical relation that:

$$P/A^{1/2} = 0.15 \pm 0.005 \text{ W/cm}$$

for standard PbSe detectors using liquid nitrogen refrigerants.

Fig. 1



Spectral Response

If the non-ohmic behavior in PbSe films is produced by Joule heating, and if the optimum D^* occurs near some temperature considerably higher than 77°K, then there should be a very significant shift in the spectral edge to shorter wavelengths. A test of the magnitude of this shift was performed using low bias powers and different refrigerants, and then increasing bias power with liquid nitrogen as a refrigerant. The results are shown in Fig. 2.

A comparison of the $\lambda_{\frac{1}{2}}$ values of curves #3 and #5 show that at high bias power and liquid nitrogen refrigerant, the spectral edge corresponds to that of the same film cooled with Freon 14 (145°K) and low bias power. Curve 2 represents the situation where the detector has its optimum spectral $D^*(\lambda_{\frac{1}{2}})$. The film temperature is approximately 105°K in this situation. Also note that the $D^*\lambda_{\max}$ at about 145°K is slightly higher than the value at 77°K. Since the error in D^* measurements can run as high as 10 percent, the variation in $D^*\lambda_{\max}$ between 105°K and 145°K is only slightly significant. The edge shift is highly significant.

If one compares the edge of the #4 curve with that of #5, the following result is obtained:

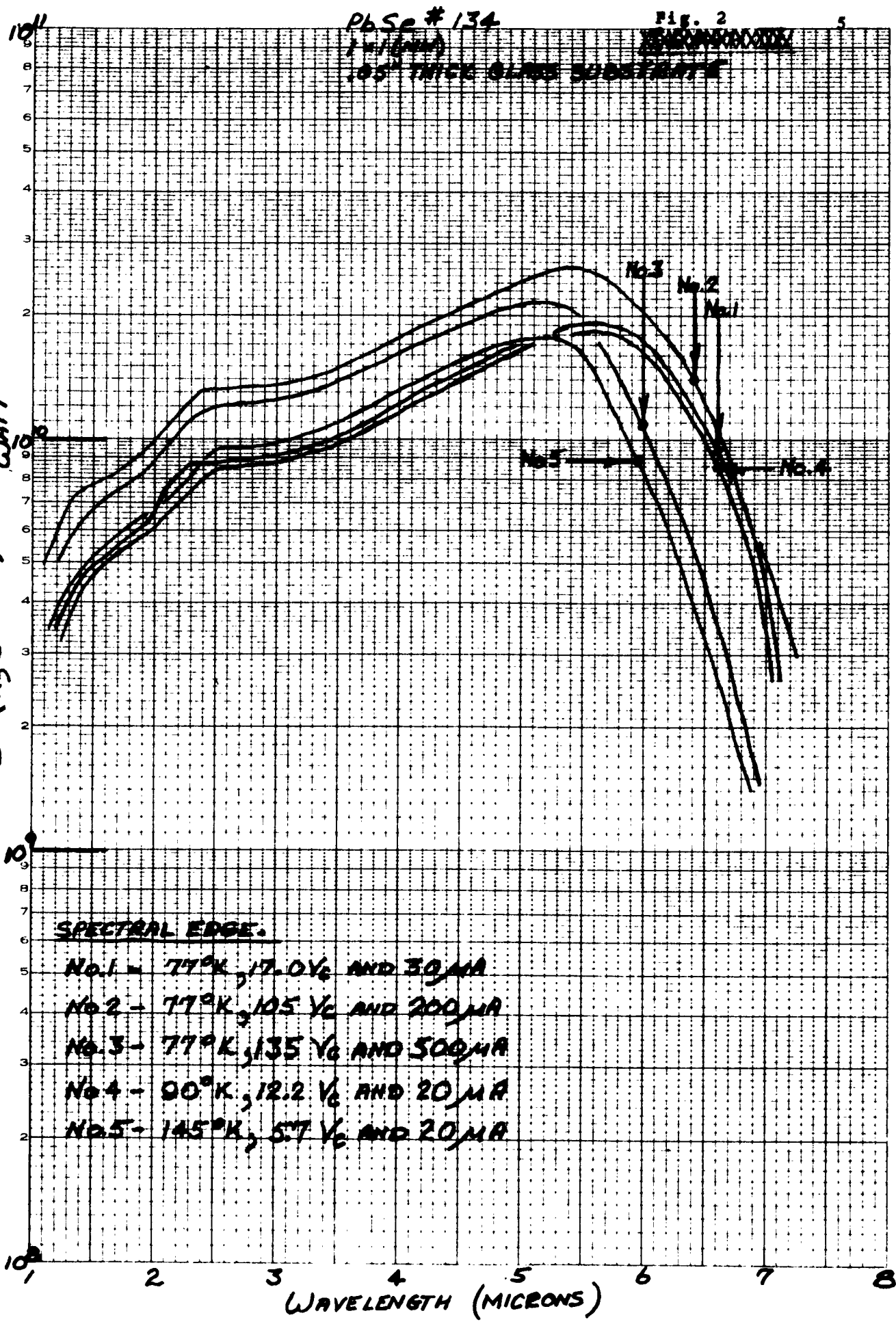
Curve	T(K°)	$\lambda_{\max}(\mu)$	$\epsilon(\text{ev})$
4	90	6.60	0.187
5	145	5.95	0.208

Therefore, $\Delta \epsilon / \Delta T = + \frac{21 \times 10^{-3}}{55} = 3.8 \times 10^{-4} \text{ eV/°K}$, which is in good agreement with previously published values.³

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$D^*(\lambda, 18000\text{cps})$ IN $\frac{\text{CY}(\text{CPS})^{1/2}}{\text{WATT}}$



An analysis of the film temperature versus bias power is presented in Fig. 3. D^* (λ_{\max}) values also are shown for interest. In certain cases where spectral performance to 6.6 microns is mandatory, it may be necessary to provide better heat sinking than presently used. In this event, the use of a sapphire sub-substrate and a thin strontium titanate substrate are recommended so that the thermal dissipation can be greatly improved. In most cases, the present heat sinking is adequate since the use of the detector beyond about 5.2 microns is normally not desired. It is also important to note that excessive bias power in the film can affect the lifetime (time constant) of the detector. This consideration must be remembered when applying the detector in a circuit requiring amplifier boost to compensate for signal roll-off with frequency.

AC Hall Measurements on PbSe Films

AC Hall and conductivity measurements as functions of temperature for Hall sample #3160-3-4 were reported in Fig. 1 of the first quarterly report of this program. During this quarter additional measurements have been made using another Hall sample from this same deposition. The results of these measurements are shown in Fig. 4. The general characteristics of the results for this sample (3160-3-5) are similar to the results for sample 3160-3-4. However, there is one distinct difference. The effective mobility (μ^*) curve of 3160-3-5 exhibits a change in slope below about 145°K. The major known difference in the two samples is a difference in the results of the sensitization. The recent sample has a higher D^* after sensitization; viz, a $D^*(500^\circ\text{K})$ of about $5.5 \times 10^9 \text{ cm}(\text{cps})^{1/2}/\text{watt}$ compared to about $3.4 \times 10^9 \text{ cm}(\text{cps})^{1/2}/\text{watt}$.

These initial Hall measurements were made on sample 3160-3-5, while sealed to an all glass vacuum system. The sample was then allowed to rest in the vacuum environment ($\sim 10^{-6}$ Torr) for a

4002-134

Fig. 3

Pb 50 1x1 (mm)



PLATE 17/10-3-8
Oct 31, 1962
100° Field of View
300° K Background

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μ (cm²/Vt-sec)

P (a/cm)

carriers/cm³

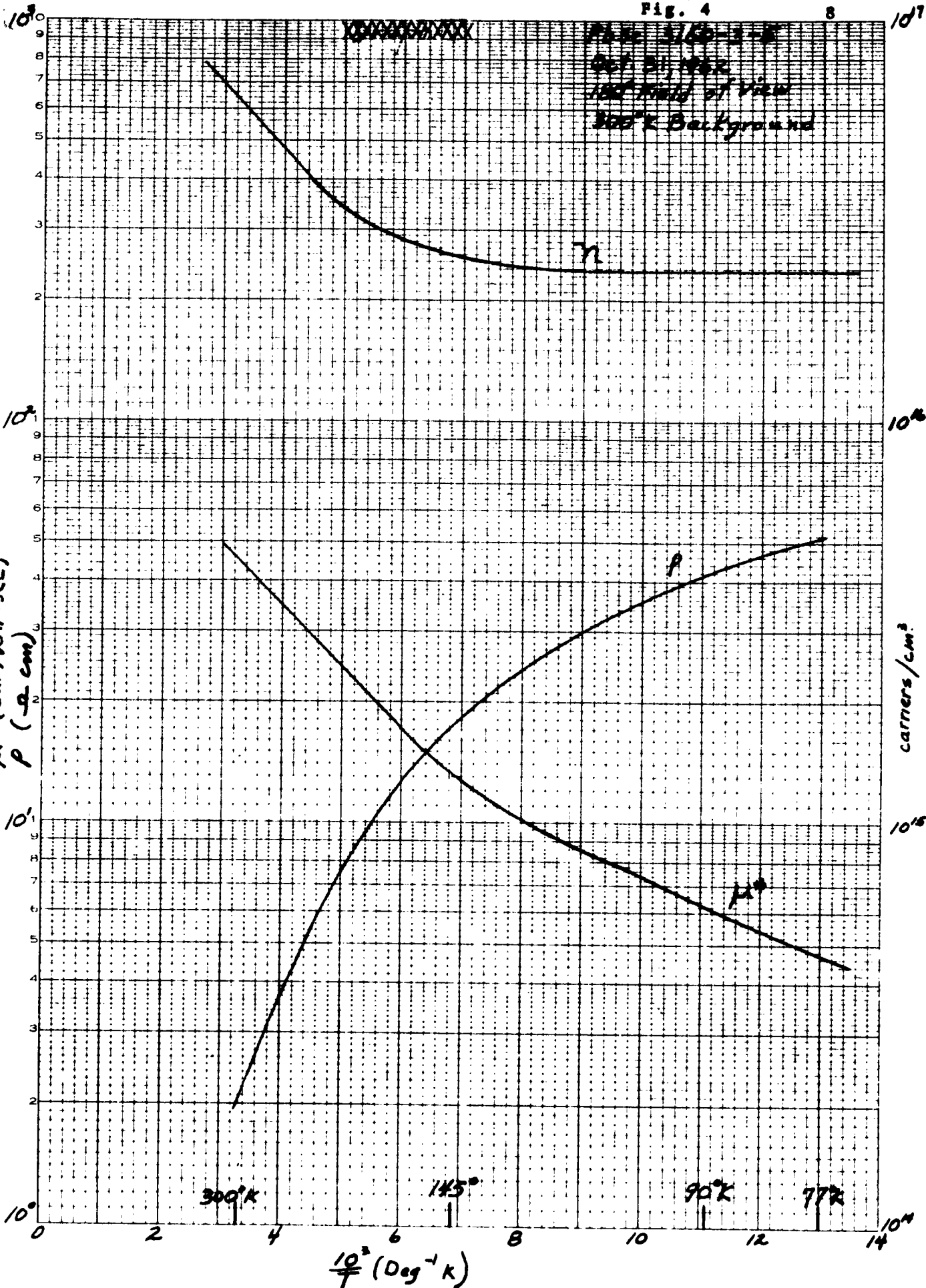
300°K

145°

90°K

77°K

$\frac{10^3}{T}$ (Deg⁻¹ K)



period of 35 days, during which time several checks of the electrical characteristics were made. Figure 5 presents the results of this high vacuum storage. Previous experience has demonstrated that high vacuum storage of unprotected (uncoated) PbSe films causes the resistance to rise considerably. This experiment establishes that this rise is caused by a decrease in carrier concentration; the mobility is not greatly affected by the high vacuum storage. Previous experiments have already demonstrated that the increased resistance on vacuum storage is associated with a desorption of H_2O from the surface of the film. Figure 6 shows the temperature dependence of ρ , n , and μ^* after the 35 day storage. It should be understood that n was obtained from the Hall coefficient (R_H) using the extrinsic relation that $n = 1/R_H e$.

The effect of background radiation on the electrical characteristics of PbSe films is important as it relates to the basic mechanism of photoconductivity in these films. The fundamental question is whether the photoresponse from these films is caused by a photomodulation of the effective number of carriers in the film, or by a photomodulation of the barriers between the grains composing the film.

The first preliminary experiment was performed to obtain an insight into the mechanism. The liquid nitrogen cooled film was exposed to a globar operating at 500°K and the results on the resistance and Hall coefficient were observed. The resistance was decreased by a factor of 1.9. The Hall coefficient did not appear to change outside the magnitude of experimental error. Consequently, the effective mobility was raised by a factor of about 1.9 by the uncalibrated radiation from this globar.

The second experiment included covering the film with a three micron interference-type cutoff filter to restrict 300°K background radiation, and then making Hall measurements versus temperature. This type of cold optical filtering should reduce

Fig. 5

10

10^{17}

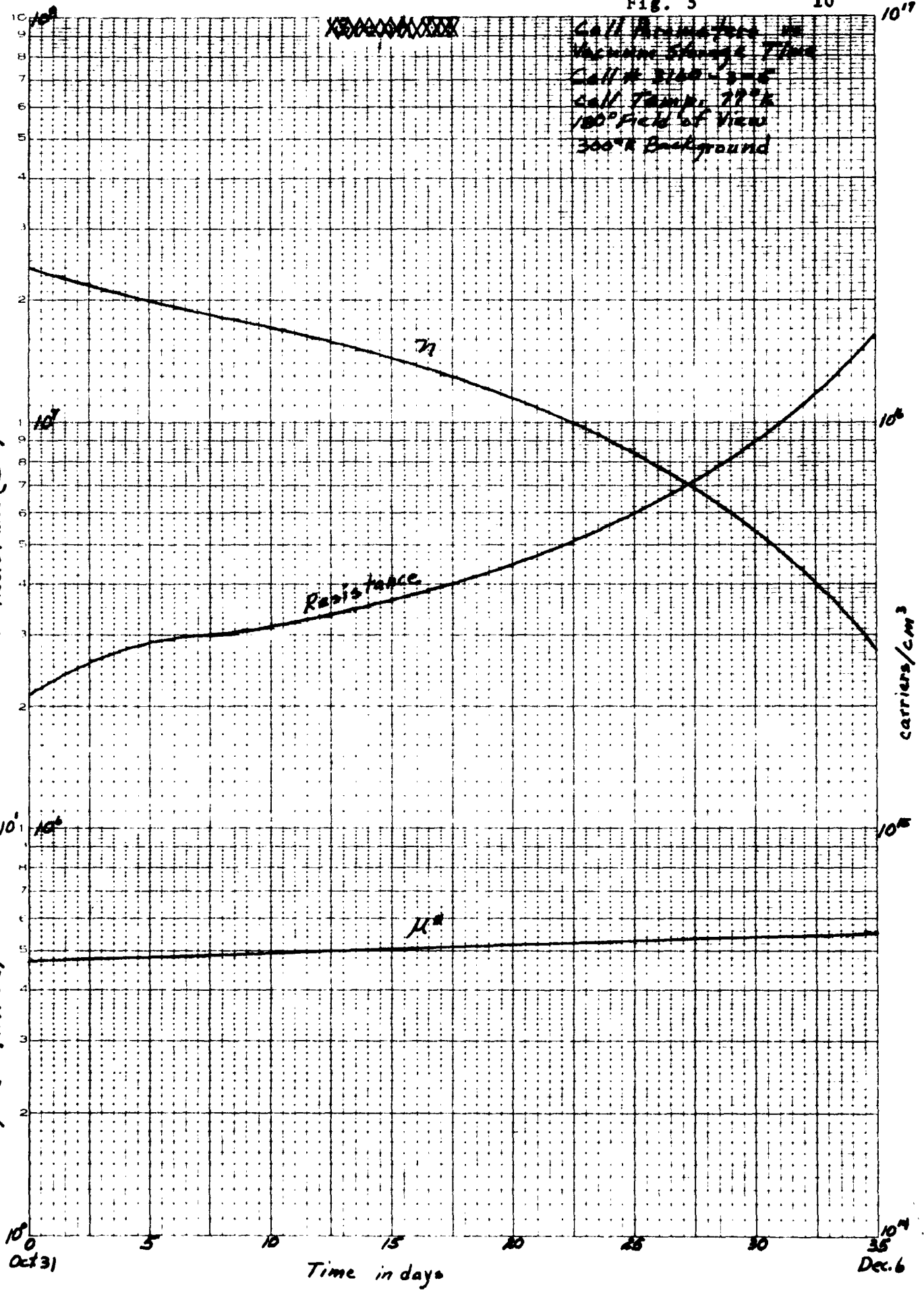
Cell Parameters in
Vacuum Storage Time
Cell # 3100-1-1
Cell Temp. 77°K
 100° Field of View
 300°K Background

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WASHINGTON, D.C.
SEMICONDUCTOR DIVISION

Cell Resistance (Ω)

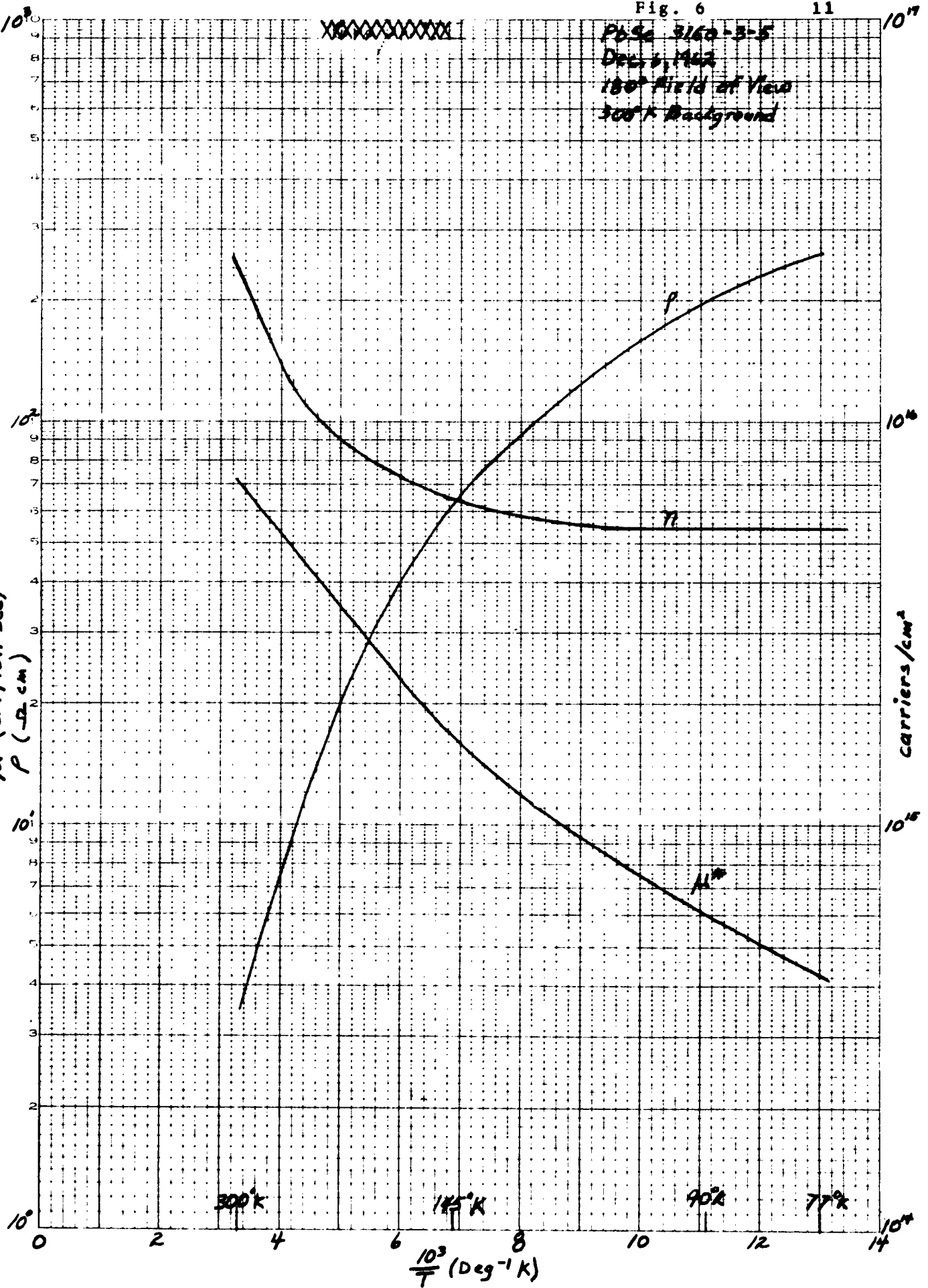
$\mu^2 (\text{cm}^2/\text{volt}\cdot\text{sec})$

carriers/ cm^3



Time in days

Dec. 6

10¹⁷

the background photon flux by a factor of 1400 and still permit detectivity and lifetime measurements. Unfortunately, after observing only a minor time constant change of a factor of three, a spectral transmission indicated that this filter had a secondary transmission spike at six microns sufficient to admit a significant amount of 300°K radiation. A total cold shield was then mounted in front of the film to restrict all radiation except that emitted by the shield which was very close to the film temperature. The measurements are shown in Fig. 7. One can summarize these preliminary results by a few qualitative statements:

- 1) The most significant observation is that a reduction in background radiation increases the carrier concentration. In the case of extrinsic BLIP detectors, the carrier concentration would be decreased by a decrease in background radiation. The observed increase in hole concentration must then be associated with the increased carrier lifetime that accompanies the decrease in background.

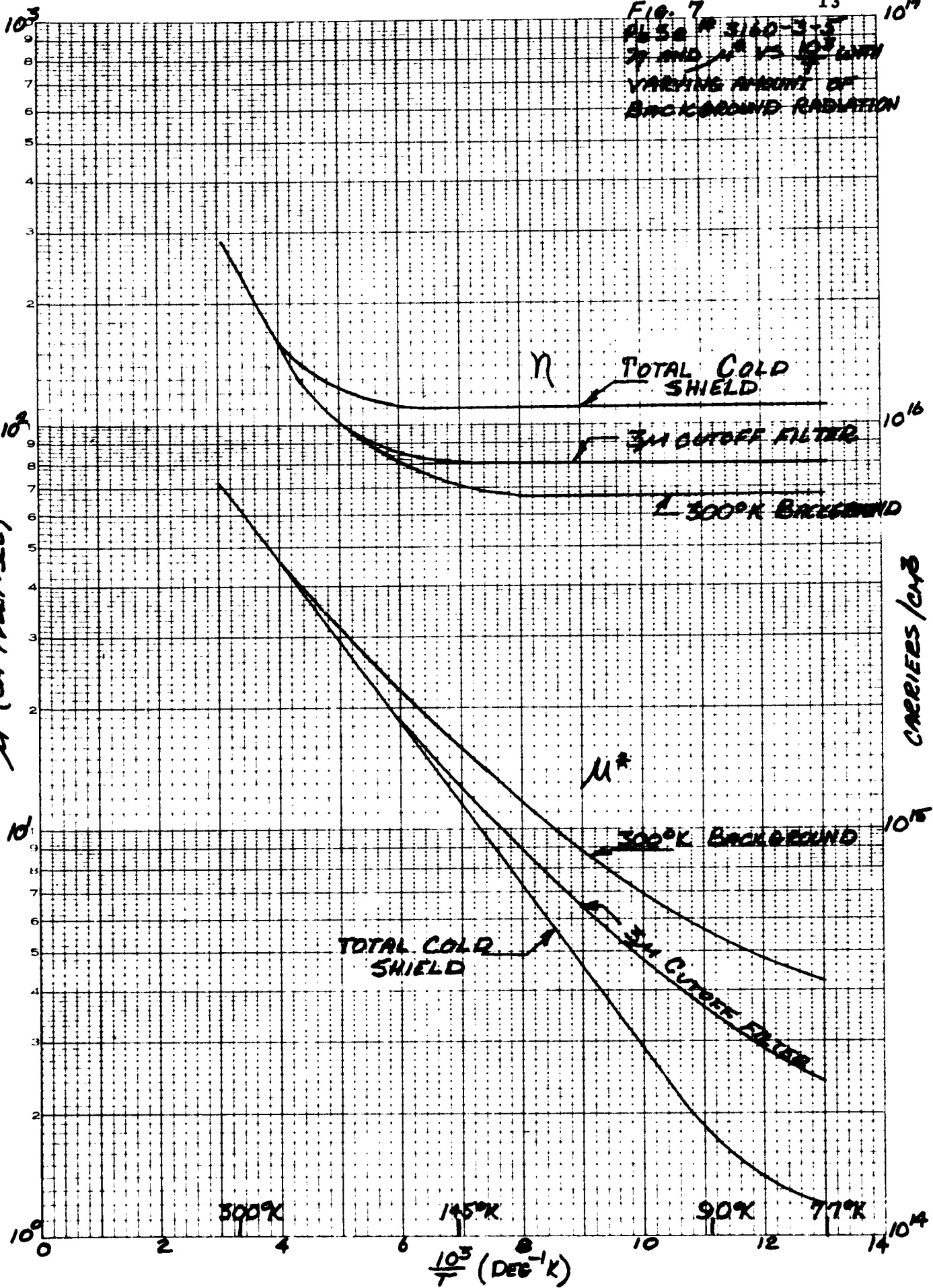
- 2) Decreasing the background radiation greatly decreases the mobility. The implication here is that the effective barrier height between grains is increased when the background decreases and the carrier lifetime increases. Detailed explanation of these preliminary results must be postponed until further data, supporting the validity of these results, have been obtained and more quantitative support of the observed changes has been provided.

Figure 8 shows the temperature dependence of the Hall sample lifetime for both the wide open and filtered cases. Obviously, it is impossible to measure the lifetime of the totally shielded case. Note that the lifetime increases by a factor of three with the insertion of the "leaky" filter. Further experiments with better filters will be necessary to establish the upper limit on lifetime. One can postulate that, depending on the trapping mechanism

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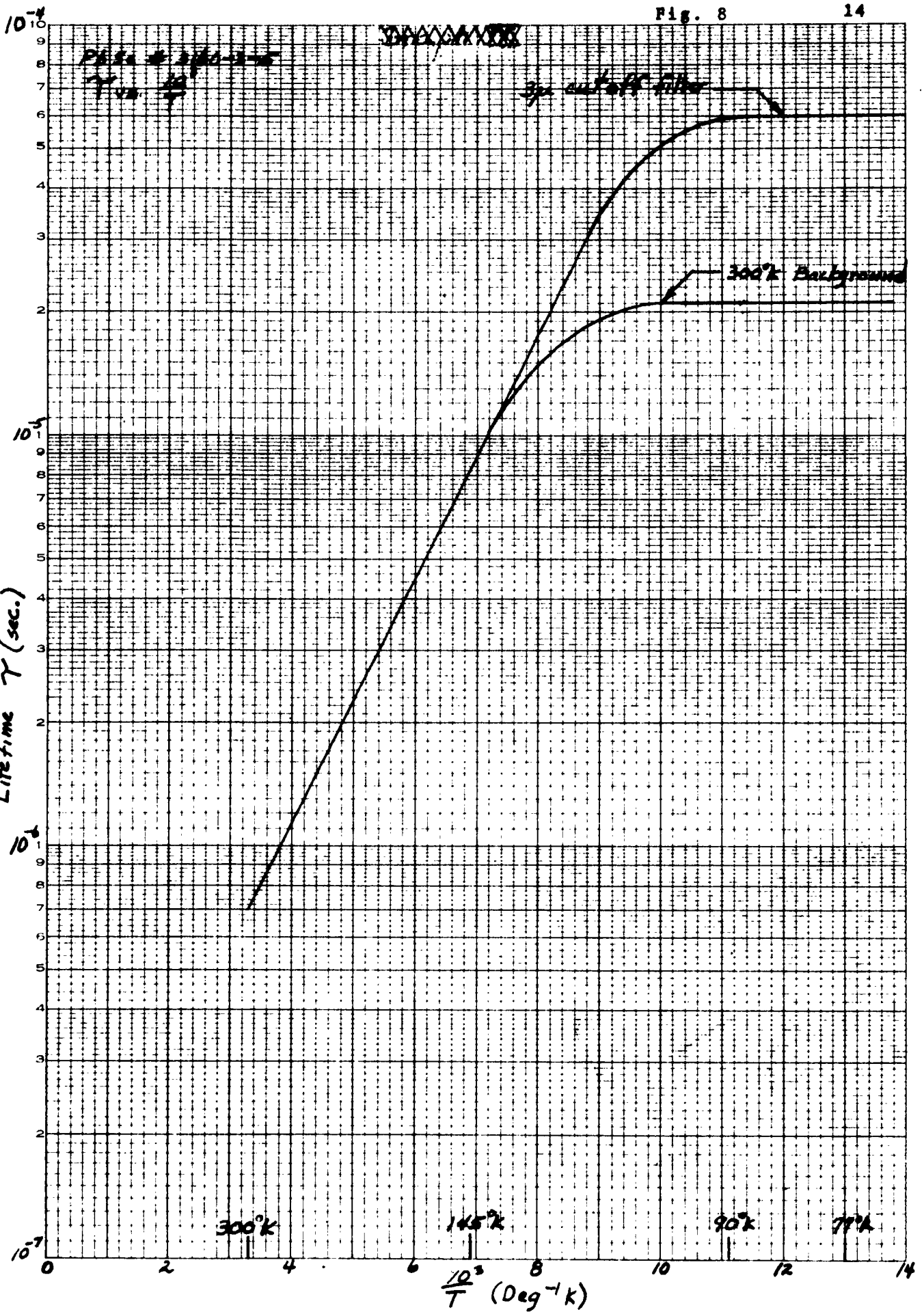
$\mu^* (\text{CM}^2/\text{VOLT}\cdot\text{SEC})$



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Lifetime γ (sec.)



involved, the upper limit of the photoconductive lifetime may be associated with the radiative recombination lifetime in the PbSe lattice.

II NEW TECHNIQUE FOR DETECTOR IMPROVEMENT

As discussed on page five of the first quarterly report, a new technique for improving PbSe detectors has been discovered in the detector engineering section of the company as part of a company sponsored general research program. Preliminary results were quite encouraging, because the method reportedly decreased the film resistance by as much as an order of magnitude without degradation in D^* . Since preliminary results based on small samples are often erroneous, it was decided that, as part of this program to check the validity of the early results, a controlled experiment involving larger sample sizes should be evaluated. The alleged improvement technique involves the carbonization of the film by coating it with a thin coating of dextrose solution prior to heat treat sensitization. This process will be referred to as the "DD" process.

The first experiment was performed in the following manner:

- 1) Twelve units were selected from a fresh PbSe deposition.
- 2) These units were divided into two equal groups.
- 3) One group was subjected to the DD process and sensitized.
- 4) The other group was sensitized in the usual manner as controls.
- 5) Tests of samples from both groups were made in a standard test flask.

The comparative results between the DD units and controls indicate no significant difference between the two groups. However, the resistance spread was large and the detectivities of both groups were inferior. Since this is a well recognized problem involving the yield of good depositions, it was decided that a second run should be performed to give the process the benefit of any doubt.

The results of this experiment are also negative. It has been concluded that the DD group is not significantly different from the control group. Consequently, no further consideration of this technique is anticipated.

The Effect of Nuclear Radiation on Infrared Detectors

During early October, an assortment of infrared detectors was delivered to the Nuclear Effects Department of the Hughes Aircraft Company at Fullerton. Cooperative experiments were planned to make a comparison of the performance of various infrared detectors when subjected to the radiation emanating from the Hughes linear accelerator at Culver City. The instrumentation for these experiments would be conducted by the Fullerton group under sponsorship of the same contracting agency. SBRC would supply the assortment of necessary detectors and provide whatever assistance would be necessary whenever the instrumentation was completed and time on the Linac was available. The first experiments of this nature were conducted during December. Certain difficulties with some of the detectors were experienced. Further tests are contemplated for January and will be scheduled for a period when the Linac will be available to complete these measurements. The details of the recent measurements will be included with the results obtained in January and will be discussed in the next quarterly report.

III SUMMARY

- 1) Joule heating of cooled PbSe films by the bias power is the chief cause of non-ohmic behavior in standard PbSe detectors.
- 2) The optimum bias power/area^{1/2} of a standard PbSe detector is 0.15 ± 0.05 watt/cm.
- 3) Since the exact location of the spectral edge is temperature dependent, it is important to use a bias power considerably below optimum if performance to 6.6 microns is mandatory.

4) The AC Hall coefficient of cooled PbSe films appears to decrease as the background radiation falling on the film decreases.

5) The AC Hall coefficient increases as a PbSe film is exposed to high vacuum over an extended period of time so that H_2O can be very slowly desorbed from the surface of the film.

6) The effective carrier mobility in a PbSe film increases with an increase in background radiation, and decreases with a decrease in background radiation.

7) Controlled experiments using a new sensitizing technique does not yield any significantly better results.

8) Cooperative experiments on the effect of nuclear radiation on various types of infrared detectors are underway at HAC-Fullerton and Culver City.

IV WORK FOR NEXT PERIOD

1) Obtain more quantitative information on the effect of background radiation on the electrical characteristics of PbSe films.

2) Continue the cooperative evaluation of the effect of adverse nuclear radiation on the performance of various types of infrared detectors.

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R. M. Talley, Manager
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1. D. E. Bode and H. A. Graham, Proc. IRIS, Vol 7, No. 2 (1962) pp 161-166.
2. op cit. p 163.
3. Richard H. Bube, Photoconductivity of Solids, John Wiley & Sons (1960) p 237.